MYOPIC SEARCH PLANS

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THESIS

MYOPIC SEARCH PLANS

by

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This thesis documents interactive computer programs that are useful for testing search strategies against the myopic strategy, and shows examples where the myopic strategy is not optimal.

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Myopic Search Plans

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ABSTRACT

Different strategies can be used to search for a moving object.

If the searcher's action at each time unit maximizes his chances of immediate detection, his strategy is said to be myopic. If, however, the searcher seeks to allocate search effort to maximize the probability of detecting the traget within a preset amount of time, his strategy is called optimal.

This thesis documents interactive computer programs that are useful for testing search strategies against the myopic strategy, and shows examples where the myopic strategy is not optimal.

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I. INTRODUCTION

A search is an operation with the purpose of finding an object (target) that will in the thesis be assumed to move during the search.

In general, it will be assumed that the target is within an area that can be partitioned into a finite number of cells, moving from one cell to another at fixed time intervals (periods). The actual path that the object follows, whenever it moves, is unknown but the probabilistic distribution of all possible paths is given. It is assumed that the cells which the target will occupy in the future depend only on the cell it is in at the present time but not on how it got there (markovian motion).

If the searcher allocates his resources to maximize the chances of immediate detection, his search plan is said to be myopic. If, however, he seeks to allocate search effort to maximize the probability of detection within a preset amount of time, his plan is called optimal.

In an important class of naval search problems, the target probabilistic distribution over space, i.e., the initial probability of it being in each cell is known. If resources are allocated to some cells, a new distribution over space is to be considered after an unsuccessful search, according to Bayes' theorem.

Formally, it is assumed that the following are given:

a) A set C of states.

b) A set A of actions.

c) An apriori distribution $P_1(c)$ defined on C with $P_1(c)$ being the probability that the target is initially in state c.

d) A function $Q(a,c)$ being the probability of no detection if action a is taken when target is in state c.

e) A function $M(c/d)$ being the probability that the state of the target changes from d to c between actions. Since only the current state d is relevant to determine c, the target motion is markovian.

Let $a_1, a_2, \ldots, a_t$ be a sequence of actions.

Let $P'_t(c)$ be the probability distribution of the state of the target conditioned on non-detection by $a_1, a_2, \ldots, a_t$ and t-1 state changes, and $P_{t+1}(c)$ be the probability distribution conditioned on non-detection by $a_1, a_2, \ldots, a_t$ and t state changes.

Then, according to Bayes theorem,

$$P'_t(c) = \frac{P_t(c)Q(a_t,c)}{\sum_d P_t(d)Q(a_t,d)} \tag{1}$$

and according to the motion model

$$P_{t+1}(c) = \sum_d P'_t(d)M(c/d) \tag{2}$$

Since $P_1(c)$ is given, alternative applications of (1) and (2) will provide $P_t(c)$ for all t.

The probability of detection during period t, conditioned on earlier failures is

$$P_t = \sum_d P_t(d)[1 - Q(a_t,d)]$$

If a_t is chosen to maximize P_t for $t = 1,2, \ldots$ in succession, then a_t is a myopic plan.

The probability that the target has not been detected until the end of the T^{th} period is

$\overline{P}(T)$ = P[target not detected at period 1, and not detected at period 2, and ..., and not detected at period T]

$$\overline{P}(T) = \prod_{t=1}^{T} (1 - P_t) = \prod_{t=1}^{T} [\sum_d P_t(d) Q(a_t,d)]$$

Then, the probability of detection after T actions

$$P(T) = 1 - \overline{P}(T) = 1 - \prod_{t=1}^{T} [\sum_d P_t(d) Q(a_t,d)]$$

a_t is an optimal plan if it maximizes P(T) for a given T.

Optimal plans are highly complex and consequently expensive to find [1]. In contrast, myopic plans are easy to find.

The myopic strategy may be optimal, as in the case of stationary targets, or near optimal, as in most of the examples in references [1] and [2].

There are however, cases for which myopic plans are strongly non-optimal.

Models are to be constructed and used to reach the main goals of this thesis:

1) Develop and implement an algorithm to find myopic plans.

2) Create interactive search programs, and

3) Use them to discover classes of problems for which the myopic strategy is strongly non-optimal.

II. THE MODELS AND ASSUMPTIONS

A. SPACE MODEL

Space is divided into mxn square cells, each one identified by a 2-tuple. The upper left cell is cell (1,1). Cell (i,j) is the i^{th} cell to the east, j^{th} cell to the south.

If it happens that a target cannot move in some directions, boundaries can be introduced, either reflecting or absorbing. A target cannot cross a reflecting boundary. If one of its paths leads to the outside, this path is reflected, i.e., the target moves in the opposite direction. Reflecting boundaries model, for example, the borders of a channel. An absorbing boundary can be crossed from the interior but not from outside. It models the case in which the target has some information about the search area and tries to evade. Once it is out, it will never move back into that area.

By search area it is meant the subset of cells to which the searcher is able, allowed or willing to allocate effort and that is not necessarily the same subset that the target can move across. The latter will be referred to as the target area.

B. DETECTION MODEL

Sensors are assumed to have an exponential detection function, that is, the conditional probability of detection has the form:

$$1 - \exp[-a(g,t)x(g,t)],$$

where x(g,t) is the amount of search effort allocated to cell g at period t and a(g,t) is a non-negative constant which may depend on the cell, may change with time, and that will be referred to as detection rate.

C. THE MOTION MODELS

Two models are used: the random walk in space and the random walk in speed.

In both models, speed is expressed in terms of cells per period.

If a target occupies cell (i,j) and, after a change of state it is in cell $(i+k, j+\ell)$, its speed in the west-east direction is $V_x = k$ cells/period, and its speed in the north-south direction is $V_y = \ell$ cells/period

1. Random Walk in Space

In this model, $P_t(c) = S_t(i,j)$, i.e., $P_t(c)$ is the probability of the target being in cell (i,j).

Given the joint distribution of V_x and V_y, $t_{V_x,V_y}(v_x,v_y)$, invariant with time and space,

$$S_{t+1}(i,j) = \sum_k \sum_\ell S_t(k,\ell)\, t_{V_x,V_y}(i-k, j-\ell)$$

The, for this model,

$$M(c/d) = t_{V_x,V_y}(i-k, j-\ell)$$

where i and j define state c, and the state d is defined by k and ℓ.

2. Random Walk in Speed

Sets of possible values for V_x and V_y are fixed. Let $V^x = \{v_1^x, v_2^x, \ldots, v_n^x\}$ and $V^y = \{v_1^y, v_2^y, \ldots, v_m^y\}$ be the sets of possible values that V_x and V_y can assume. $P_t(c)$ is equal to $S_t(i,j,k,\ell)$, i.e., $P_t(c)$ is the probability of the target being in cell (i,j), its speed having components, v_k^x, v_ℓ^y.

Let $P_{\Delta V_x}(\delta V_x)$ and $P_{\Delta V_y}(\delta V_y)$ be the known discrete distributions of ΔV_x and ΔV_y, the changes in V_x and V_y per period, respectively.

Given $P_{\Delta V_x}(\delta V_x)$ a matrix P^x can be constructed, which entries $p_{i,j}^x$ are the probabilities of V_x changing from v_i^x to v_j^x in one period. A similar matrix P^y can be constructed which entries are the probabilities of the changes in V_y. Then

$$S_{t+1}(i,j,k,\ell) = \sum_r \sum_s S_t(i-r,j-s,r,s)\, p_{r,k}^x\, p_{s,\ell}^y \; .$$

III. MYOPIC SEARCH PLANS

Let p_i, $i = 1,2, \ldots, n$ be the probability of the target being in the i^{th} of the n cells among which the search effort is to be myopically distributed at period t.

Let x_i, $i = 1,2, \ldots, n$ be the fraction of effort allocated to each of the cells that are assumed to have a common detection rate a which may change with periods.

Given the detection model, a myopic plan maximizes

$$\sum_i p_i(1 - e^{-ax_i}) \ , \quad i = 1,2, \ldots, n$$

for each $t = 1,2, \ldots$ in succession.

The sum of all x_i must not exceed X, the total amount of effort available in the period and no x_i can be less than 0.

Thus, a myopic plan is the solutions of a sequence of non-linear programs with the form

$$\text{Min} \quad \sum_i p_i e^{-ax_i} \tag{1}$$

$$\text{S/T} \quad \sum_i x_i \leq X \tag{2}$$

$$x_i \geq 0 \ , \quad i = 1,2, \ldots, n \tag{3}$$

It can be easily proved that equality holds for (2) at optimality.

If the constraints (3) are relaxed and Lagrange method is used:

$$L(x,\lambda) = \sum_i p_i e^{-ax_i} + \lambda(\sum_i x_i - X)$$

$$\frac{\partial L}{\partial x_i} = -ap_i e^{-ax_i} = 0 \qquad (4)$$

$$\frac{\partial L}{\partial \lambda} = \sum_i x_i - X = 0 \qquad (5)$$

From (4)

$$\lambda = ap_i e^{-ax_i}$$

$$\ln \lambda = \ln(ap_i) - ax_i \qquad (6)$$

$$x_i = \frac{\ln a}{a} + \frac{\ln p_i}{a} - \frac{\ln \lambda}{a} \qquad (7)$$

Sum (6), side by side, over all i:

$$n \ln \lambda = \sum_i \ln(ap_i) - a \sum_i x_i \qquad (8)$$

Substitute X for $\sum_i x_i$ in (8) and rearrange:

$$\ln \lambda = \ln a + \frac{1}{n} \ln[\prod_i p_i] - \frac{aX}{n} \tag{9}$$

Substitute (9) for ln λ in (7):

$$x_i^* = \frac{\ln a}{a} + \frac{\ln p_i}{a} - \frac{1}{a}[\ln a + \frac{1}{n}\ln(\prod_i p_i) - \frac{aX}{n}]$$

$$x_i^* = \frac{\ln p_i}{a} - \frac{1}{an} \ln[\prod_i p_i] + \frac{X}{n}, \quad i = 1,2, \ldots, n \tag{10}$$

Brown [2] proved that the objective function is convex. Then (10) is the optimal solution of the N.L.P. (1), (2). At optimality,

$$p_i e^{-ax_i} = \frac{\lambda}{a} = \text{constant for } i = 1,2, \ldots, n .$$

A. ALGORITHM FOR FINDING MYOPIC PLANS

Provided the detection rate is invariant with cells:

Step 1) Let $I = \{i: i = 1,2, \ldots, n\}$ be the set of indexes of all cells among which the search effort is to be myopically distributed.

Step 2) Solve the N.L.P. (1), (2):

$$x_i = \frac{\ln p_i}{a} + \frac{X}{m} - \frac{\ln P}{am}, \quad i \in I$$

where $P = \prod_{i \varepsilon I} p_i$ and m is the number of elements in I.

If $x_i \geq$ for all $i \varepsilon I$, stop.

Step 3) Select the cell with smallest p_i, $i \varepsilon I$. Remove its index from I and make $x_i = 0$

Go to step 2.

At optimality, $p_j \leq p_i e^{-ax_i^*}$ = constant, for all $j \notin I$, all $i \varepsilon I$.

The algorithm has at most n interactions. It solution is feasible for the N.L.P. (1), (2), (3) since

$$x_i^* = 0 \quad i \notin I$$

$$x_i^* \geq 0 \quad i \varepsilon I$$

$$\sum_i x_i = X$$

and is also optimal.

Let $Z^* = p_1 + p_2 + \ldots + p_j + p_{j+1}e^{-ax_{j+1}} + \ldots + p_{j+m}e^{-ax_{j+m}}$

where $j+m = n$, be the optimal solution produced by the algorithm after reindexing the cells such that $p_i < p_{i+1}$ for all i.

Then, the algorithm found

$$x_j = \frac{\ln p_j}{a} + \frac{X}{m+1} - \frac{\ln P'}{a(m+1)} \leq 0 \qquad (11)$$

where

$$P' = \prod_{i=j}^{j+m} p_i .$$

Suppose the optimal solution was

$$\hat{Z}^* = p_1 + p_2 + \ldots + p_{j-1} + p_j e^{-ax_j'} + p_{j+1} e^{-ax_{j+1}'} + \ldots + p_{j+m} e^{-ax_{j+m}} .$$

In this case,

$$p_j e^{-ax_j'} = p_{j+1} e^{-ax_{j+1}'} = \ldots = p_{j+m} e^{-ax_{j+m}'}$$

and

$$\ln p_j - ax_j' = \ln p_{j+1} - ax_{j+1}'$$

$$\ln p_j - ax_j' = \ln p_{j+2} - ax_{j+2}'$$

$$\vdots$$

$$\ln p_j - ax_j' = \ln p_{j+m} - ax_{j+m}'$$

Sum side by side:

$$m \ln p_j - amx_j' = \sum_{i=j+1}^{j+m} \ln p_i - a \sum_{i=j+1}^{j+m} x_i'$$

$$m \ln p_j - a(m+1)x'_j = \ln\left(\prod_{i=j+1}^{j+m} p_i\right) - aX$$

$$x'_j = \frac{m \ln p_j}{a(m+1)} + \frac{X}{(m+1)} - \frac{\ln P}{a(m+1)} > 0 \qquad (12)$$

where

$$P = \prod_{i=j+1}^{j+m} p_i$$

Compare (11) and (12):

$$\frac{m \ln p_j}{a(m+1)} + \frac{X}{(m+1)} - \frac{\ln P}{a(m+1)} > \frac{\ln p_j}{a} + \frac{X}{(m+1)} - \frac{\ln P'}{a(m+1)}$$

Since $a(m+1) > 0$

$$m \ln p_j - \ln P > (m+1) \ln p_j - \ln P'$$

$$\ln P' - \ln P > \ln p_j$$

$$\ln \frac{P'}{P} > \ln p_j$$

$$\ln p_j > \ln p_j \qquad (13)$$

Since no x_i can be made 0 before x_{i-1}, (13) proves by contradiction that the solution is optimal.

IV. THE COMPUTER PROGRAMS

Two FORTRAN programs were written.

Program SRCH1 refers to the random walk in space model and allows the space to be divided into a maximum of 100 x 100 cells. Any subset of cells can be used as target and/or search areas.

In this program, a two dimensional array is defined by the FORTRAN name CELL, which entries are the probabilities of the target being in each of the cells identified by the array indexes.

Program SRCH2 refers to the random walk in speed model. A 25 x 25 x 4 x 4 array is defined by the FORTRAN name CELL. The entries of this array are the probabilities of the target being in the cells identified by the first two indexes, its speed having the components defined by the last two indexes. Thus, this program allows the space to be divided into a maximum of 25 x 25 cells and allows the sets of possible values of V_x and V_y to have at most 4 elements each. Any subset of cells can be used as target and/or search areas.

SRCH2 maps the four dimensional array into a two dimensional array called TCELL, which entries have the same meaning as the entries of the array CELL in program SRCH1.

These two dimensional arrays are printed at the beginning of each period, after their entries are coded as follows:

The highest probability is mapped onto 100; the smallest non-zero probability mapped onto 0.

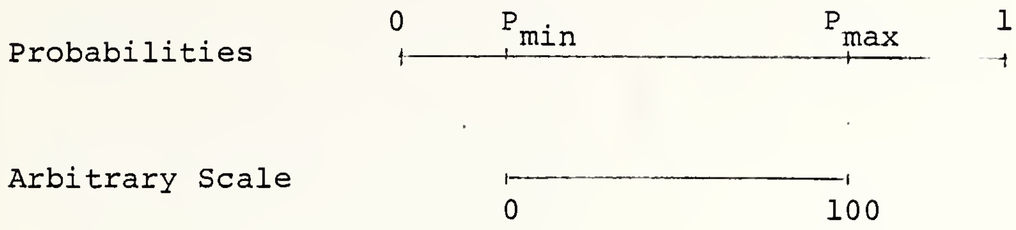

Fig. IV-1

The interval [0,100] is then divided and coded.

Subinterval	Code
100	*
[99,100)	9
[96,99)	8
[91,96)	7
[84,91)	6
[75,84)	5
[64,75)	4
[51,64)	3
[36,51)	2
[19,36)	1
[0,19)	0

Probabilities equal 0 are coded as a dot. Fig. IV-2 is an example of the coded distribution of the target.

```
RANGE OF PROBABILITIES  0.29119E-07  0.17087E-01

    30         40         50

     0123456789012345678901234

     -------------------------

27/  0000000000000000000000000
28/  0000000000000000000000000
29/  0000000011111111100000000
30/  0000001122233322211000000
31/  0000011223333333221100000
32/  0000012234444444322100000
33/  0000012345677765432100000
34/  000000124578*875421000000
35/  0000000123455543210000000
36/  .00000001122222110000000.
37/  ..000000000000000000000..
38/  ...0000000000000000000...
39/  ....00000000000000000....
40/  .....000000000000000.....
```

Fig. IV-2

Both programs have a subroutine that distributes myopically the search effort, provided the detection rate is invariant with space within the search area.

Instructions on use of the programs constitute Appendices A and B.

V. EXAMPLES AND CONCLUSIONS

A. EXAMPLES

Different situations were analysed and some of them are now presented.

1. First Example

The a priori distribution of a target was uniform over a 3 x 3 cell area as follows:

	30	31	32
30	1/9	1/9	1/9
31	1/9	1/9	1/9
32	1/9	1/9	1/9

The search areas was coincident with the above area and the target area was the entire space.

The target moved as follows:

V_x	V_y	$P(V_x=v_x, V_y=v_y)$
1	0	0.25
1	1	0.50
0	1	0.25

Five units of search effort were available and the detection rate was one for the cells within the search area, both values invariant with time.

A myopic and an alternative strategy were used which distributed effort as follows:

PERIOD 1

CELL	STRATEGY MYOPIC	ALTERNATIVE
(30,30)	0.5556	-
(31,30)	0.5556	-
(32,30)	0.5556	1.0
(30,31)	0.5556	-
(31,31)	0.5556	-
(32,31)	0.5556	1.0
(30,32)	0.5556	1.0
(31,32)	0.5556	1.0
(32,32)	0.5556	1.0

PERIOD 2

CELL	STRATEGY MYOPIC	ALTERNATIVE
(32,30)	-	0.313
(31,31)	1.25	-
(32,31)	1.25	1.527
(30,32)	-	0.313
(31,32)	1.25	1.527
(32,32)	1.25	1.32

PERIOD 3

	STRATEGY	
CELL	MYOPIC	ALTERNATIVE
(31,31)	0.6781	-
(32,31)	1.4071	1.567
(31,32)	1.4071	1.526
(32,32)	1.5076	1.907

PERIOD 4

	STRATEGY	
CELL	MYOPIC	ALTERNATIVE
(32,31)	1.4331	1.4241
(31,32)	1.4331	1.3205
(32,32)	2.1337	2.2554

PERIOD 5

	STRATEGY	
CELL	MYOPIC	ALTERNATIVE
(32,32)	5.0	5.0

The probabilities of detection were, after each period were:

	STRATEGY	
PERIOD	MYOPIC	ALTERNATIVE
1	0.42624	0.35118
2	0.60819	0.56827
3	0.65128	0.69634
4	0.65790	0.71282
5	0.65814	0.71338

After 5 periods the alternative plan yielded a probability of detection 8.39% higher. This alternative strategy consisted in distributing myopically the effort among the cells adjacent to the boundaries of the search area in the direction of the movement of the target. It made a barrier that the target had to cross to leave the search area.

This example suggested that myopic strategy was strongly non-optimal for cases in which the target could move to a safe region, and the search lasted long enough for it to reach this region.

This example led to the hypothesis that myopic plans were also strongly non-optimal in situations where the target moved to areas where the conditional probability of detection was a strong function of space, the aforementioned example being the extreme case of conditional probability of detection equal zero. However, for other analysed problems, in which the target could also evade to a safe area, no strategies could be found that led to a probability of detection

as much as 4% higher than the probability produced by myopic strategies.

2. <u>Second Example</u>

The a priori distribution of a target was uniform over a 5 x 4 cell area as follows:

	40	41	42	43	44
22	0.05	0.05	0.05	0.05	0.05
23	0.05	0.05	0.05	0.05	0.05
24	0.05	0.05	0.05	0.05	0.05
25	0.05	0.05	0.05	0.05	0.05

The target area was the subset of cells (i,j) such that $38 \leq i \leq 40$, and the search area was such that $j \leq 28$.

The target moved as follows:

v_x	v_y	$P(V_x=v_x, V_y=v_y)$
-1	1	0.3
0	1	0.4
1	1	0.3

Five units of search effort were available and the detection rate was one for the cells within the search area, both values invariant with time.

The interesting point about this case is that four different strategies turned out to be better than the myopic for a seven peeriod search.

The strategies distributed effort as follows:

PERIOD 1

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(40,22)	0.2500	-	-	-	0.2500
(41,22)	0.2500	-	-	-	0.2500
(42,22)	0.2500	-	-	-	0.2500
(43,22)	0.2500	-	-	-	0.2500
(44,22)	0.2500	-	-	-	0.2500
(40,23)	0.2500	-	-	-	0.2500
(41,23)	0.2500	-	-	-	0.2500
(42,23)	0.2500	-	-	-	0.2500
(43,23)	0.2500	-	-	-	0.2500
(44,23)	0.2500	-	-	-	0.2500
(40,24)	0.2500	-	-	-	0.2500
(41,24)	0.2500	-	-	-	0.2500
(42,24)	0.2500	-	-	-	0.2500
(43,24)	0.2500	-	-	-	0.2500
(44,24)	0.2500	-	-	-	0.2500
(40,25)	0.2500	1.0000	1.0000	1.0000	0.2500
(41,25)	0.2500	1.0000	1.0000	1.0000	0.2500
(42,25)	0.2500	1.0000	1.0000	1.0000	0.2500
(43,25)	0.2500	1.0000	1.0000	1.0000	0.2500
(44,25)	0.2500	1.0000	1.0000	1.0000	0.2500

PERIOD 2

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(40,23)	0.0360	-	-	-	0.0360
(41,23)	0.3927	-	-	-	0.3927
(42,23)	0.3927	-	-	-	0.3927
(43,23)	0.3927	-	-	-	0.3927
(44,23)	0.0360	-	-	-	0.0360
(40,24)	0.0360	-	-	-	0.0360
(41,24)	0.3927	-	-	-	0.3927
(42,24)	0.3927	-	-	-	0.3927
(43,24)	0.3927	-	-	-	0.3927
(44,24)	0.0360	-	-	-	0.0360
(40,25)	0.0360	0.7325	0.7325	0.7325	0.0360
(41,25)	0.3927	1.0892	1.0892	1.0892	0.3927
(42,25)	0.3927	1.0892	1.0892	1.0892	0.3927
(43,25)	0.3927	1.0892	1.0892	1.0892	0.3927
(44,25)	0.0360	0.7325	0.7325	0.7325	0.0360
(40,26)	0.0360				0.0360
(41,26)	0.3927	0.0892	0.0892	0.0892	0.3927
(42,26)	0.3927	0.0892	0.0892	0.0892	0.3927
(43,26)	0.3927	0.0892	0.0892	0.0892	0.3927
(44,26)	0.0360				0.0360

PERIOD 3

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(40,24)	0.1406				0.1406
(41,24)	0.3229				0.3229
(42,24)	0.3229				0.3229
(43,24)	0.3229				0.3229
(44,24)	0.1406				0.1406
(39,25)		0.0304	0.0304	0.0304	
(40,25)	0.1406	0.7386	0.7386	0.7386	0.1406
(41,25)	0.3229	1.0448	1.0448	1.0448	0.3229
(42,25)	0.3229	1.1391	1.1391	1.1391	0.3229
(43,25)	0.3229	1.0448	1.0448	1.0448	0.3229
(44,25)	0.1406	0.7386	0.7386	0.7386	0.1406
(45,25)		0.0304	0.0304	0.0304	
(40,26)	0.1406	0.0168	0.0168	0.0168	0.1406
(41,26)	0.3229	0.0499	0.0499	0.0499	0.3229
(42,26)	0.3229	0.0499	0.0499	0.0499	0.3229
(43,26)	0.3229	0.0499	0.0499	0.0499	0.3229
(44,26)	0.1406	0.0168	0.0168	0.0168	0.1406
(40,27)	0.1406				0.1406
(41,27)	0.3229				0.3229
(42,27)	0.3229	0.0499	0.0499	0.0499	0.3229
(43,27)	0.3229				0.3229
(44,27)	0.1406				0.1406

PERIOD 4

CELL	MYOPIC	STRATEGY 1	2	3	4
(39,25)		0.2006	-	-	-
(40,25)	0.1854	0.7037	-	-	-
(41,25)	0.2930	1.0049	-	-	-
(42,25)	0.2930	1.0944	-	-	-
(43,25)	0.2930	1.0049	-	-	-
(44,25)	0.1854	0.7037	-	-	-
(45,25)	-	0.2006	-	-	-
(39,26)	-	-	0.2259	-	-
(40,26)	0.1854	0.0109	0.3666	-	-
(41,26)	0.2930	0.0109	0.3666	-	-
(42,26)	0.2930	0.0109	0.3666	-	-
(43,26)	0.2930	0.0109	0.3666	-	-
(44,26)	0.1854	0.0109	0.3666	-	-
(45,26)	-	-	0.2259	-	-
(39,27)	-	-	0.0720	0.2624	-
(40,27)	0.1854	-	0.2691	0.4594	-
(41,27)	0.2930	0.0109	0.3666	0.5570	-
(42,27)	0.2930	0.0109	0.3666	0.5570	-
(43,27)	0.2930	0.0109	0.3666	0.5570	-
(44,27)	0.1854	-	0.2691	0.4595	-
(45,27)	-	-	0.0720	0.2624	-
(39,28)	-	-	-	-	0.4636
(40,28)	0.1854	-	0.0144	0.2048	0.7500
(41,28)	0.2930	-	0.2756	0.4661	0.8576
(42,28)	0.2930	-	0.3528	0.5432	0.8576
(43,28)	0.2930	-	0.2756	0.4661	0.8576
(44,28)	0.1854	-	0.0144	0.2048	0.7500
(45,28)	-	-	-	-	0.4636

PERIOD 5

STRATEGY

CELL	MYOPIC	1	2	3	4
(39,26)	0.1551	0.2487	0.3106	-	-
(40,26)	0.2537	0.2939	0.7002	-	-
(41,26)	0.2829	0.2939	0.9634	-	-
(42,26)	0.2829	0.2939	1.0515	-	-
(43,26)	0.2829	0.2939	0.9634	-	-
(44,26)	0.2537	0.2939	0.7002	-	-
(45,26)	0.1551	0.2487	0.3106	-	-
(39,27)	0.1551	0.1902	-	0.5414	-
(40,27)	0.2537	0.2567	-	0.6122	-
(41,27)	0.2829	0.2939	-	0.6524	-
(42,27)	0.2829	0.2939	-	0.6524	-
(43,27)	0.2829	0.2939	-	0.6524	-
(44,27)	0.2537	0.2567	-	0.6122	-
(45,27)	0.1551	0.1902	-	0.5414	-
(39,28)	0.1551	0.0326	-	0.1294	0.5131
(40,28)	0.2537	0.1804	-	0.0953	0.7177
(41,28)	0.2829	0.2687	-	0.0953	0.8357
(42,28)	0.2829	0.2939	-	0.0953	0.8668
(43,28)	0.2829	0.2687	-	0.0953	0.8357
(44,28)	0.2537	0.1804	-	0.0953	0.7177
(45,28)	0.1551	0.0326	-	0.1294	0.5131

PERIOD 6

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(39,27)	0.3795	0.4157	0.5429	0.3880	-
(40,27)	0.3482	0.3398	0.5177	0.6928	-
(41,27)	0.3482	0.3398	0.5177	0.9198	-
(42,27)	0.3482	0.3398	0.5177	0.9987	-
(43,27)	0.3482	0.3398	0.5177	0.9198	-
(44,27)	0.3482	0.3398	0.5177	0.6928	-
(45,27)	0.3795	0.4157	0.5429	0.3880	-
(39,28)	0.3795	0.3851	0.2164	-	0.5516
(40,28)	0.3482	0.3398	0.1887	-	0.7049
(41,28)	0.3482	0.3398	0.1717	-	0.8167
(42,28)	0.3482	0.3398	0.1717	-	0.8535
(43,28)	0.3482	0.3398	0.1717	-	0.8167
(44,28)	0.3482	0.3398	0.1887	-	0.7049
(45,28)	0.3795	0.3851	0.2164	-	0.5516

PERIOD 7

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(38,28)	0.1225	0.1376	0.1727	0.0748	
(39,28)	0.7748	0.7845	0.8073	0.7448	0.5815
(40,28)	0.6411	0.6312	0.6080	0.6721	0.7013
(41,28)	0.6411	0.6312	0.6080	0.6721	0.7996
(42,28)	0.6411	0.6312	0.6080	0.6721	0.8352
(43,28)	0.6411	0.6312	0.6080	0.6721	0.7996
(44,28)	0.6411	0.6312	0.6080	0.6721	0.7013
(45,28)	0.7748	0.7845	0.8073	0.7448	0.5815
(46,28)	0.1225	0.1376	0.1727	0.0728	

The probabilities of detection after each period were:

		STRATEGY			
PERIOD	MYOPIC	1	2	3	4
1	0.22119	0.15803	0.15803	0.15803	0.22119
2	0.38064	0.29861	0.29861	0.29861	0.38064
3	0.49071	0.43139	0.43139	0.43139	0.49071
4	0.57188	0.55845	0.49688	0.48977	0.55116
5	0.63270	0.62597	0.62012	0.54531	0.61063
6	0.67812	0.67652	0.67891	0.66582	0.66948
7	0.70635	0.70815	0.71475	0.72319	0.72790

Strategy 4 was 3.05% better than the myopic, for a seven period search. This strategy searched myopically for the target until it could possibly be in cells adjacent to the boundaries of search area, and then, as in the first example, concentrated the effort in those cells.

B. CONCLUSIONS

Although myopic strategy is strongly non-optimal for some specific cases, as the first example in this thesis and as the problem which Brown [2] called the Island Passage Problem, no classes of problems could be characterized for which a strategy could be found that was much better than the myopic.

Many researched problems, the presented examples inclusive, show that a strategy which may not be optimal but that concentrates the effort near the boundaries of the search area when

the target reaches these boundaries, produces better results than a myopic strategy.

It should be noted that no cases were considered in which the detection rate changed with cells within the search area and none of the alternative strategies used can be guaranteed to be optimal.

C. EXTENSIONS

Extensions can be brought into this thesis that may possibly lead to the characterization of classes of problems for which the myopic strategy is strongly non-optimal.

First, an algorithm to find optimal plans may be implemented and added to the computer programs.

Second, the restriction on the change of detection rate with cells within the search area may be removed from the myopic plan.

Further, other motion model as the fleeing datum [1] and the geometric memory motion [2] can be used.

Last, a detection model in which the conditional probability of detection is a function of the speed of the target can be constructed and used together with the random walk in speed model.

APPENDIX A

INSTRUCTIONS ON USE OF PROGRAM SRCH1

The first data the program requires are the limits of the target area and types of boundaries. They must have the form

aadwwwbbbxxxcccyyydddzzz.

QUANTITY	MEANING	REQUIREMENTS
aaa	West limit	$001 \le aaa \le 100$
bbb	East limit	$001 \le bbb \le 100$; $bbb > aaa$
ccc	North limit	$001 \le ccc \le 100$
ddd	South limit	$001 \le ddd \le 100$; $ddd > ccc$
www	Type of the	
xxx	boundary which	REF for reflecting
yyy	preceeds each of	ABS for absorbing
zzz	these quantities	

Next, the program asks for the limits of the search area. The entry must have the form

aaabbbcccddd

all quantities with the same meanings and fulfilling the same requirements as above.

Then, the transition matrix is to be introduced.

If the probability of the target moving from cell (m,n) to cell $(m+k,n+\ell)$ is p_i, enter

aaabbb __p__

where

aaa = k

bbb = ℓ

__p__ = p_i

enter one line for each i, after which, enter Ø.

$\sum_i p_i$ must be equal to 1.

__p__ was the format F10.8

The last entry before calculations begin is the a priori distribution of the target, which must have the form,

eeefff __p__

where eee and fff identify the cell where the target is with probability __p__ $\neq$ Ø.

Enter one line for each __p__, after which enter Ø. __p__ must fulfill the requirements previously stated. From this point on, all actions are repeated at each period.

The program prints a table similar to that in Fig. IV-2 which shows the coded distribution of the target at the beginning of the period, and then, asks for the total amount of effort available in the period and the detection rate. Use format 2F5.3 to introduce these values.

In case the user does not want a myopic distribution, the effort is to be distributed as follows:

eeefff___t__

where eee and fff identify the cell where the amount _t_ is placed.

Enter one line for each _t_ $\neq 0$.

Summation of all _t_ must add up to the total amount of effort available in the period.

_t_ has the format F10.8.

Enter Ø after distributing the search effort.

Questions must be answered Yes (Y) or No (N) as in the following example:

```
 $ srchl
EXECUTION BEGINS...
 ENTER LIMITS OF TARGET AREA AND TYPE OF BOUNDARIES
>025ref030ref020abs025ref
 ENTER LIMITS OF SEARCH AREA
>025030001100
 ENTER TRANSITION MATRIX
>000-010.25
>0000010.25
>0010000.25
>-010000.25
>0
 ENTER A PRIORI DISTRIBUTION OF TARGET
>0260220.3
>0260230.4
>0270230.3
>0
 RANGE OF PROBABILITIES   0.30000    0.40000
     26
     67
     --
 22/ 0.
 23/ *0
 ENTER TOTAL EFFORT AND DETECTION RATE
>3.0001.000
 MYOPIC PLAN?
>Y
```

```
 WANT TO KNOW DISTRIBUTION OF EFFORT?
>Y
  CELL   EFFORT
 26  22  0.9041
 26  23  1.1918
 27  23  0.9041
 AFTER 1 PERIODS, PROB DET IS  0.63559
 WANT TO CONTINUE?
>Y
 RANGE OF PROBABILITIES   0.833333$-01  0.16667
     25
      5678
      ---
 21/ .0..
 22/ 00*.
 23/ 0*00
 24/ .00.
 ENTER TOTAL EFFORT AND DETECTION RATE
>3.0001.000
 MYOPIC PLAN?
>n
 ENTER DISTRIBUTION OF SEARCH EFFORT
>0270221.5
>0260231.5
>0
 AFTER 2 PERIODS, PROB DET IS  0.72995
 WANT TO CONTINUE?
>n
 WANT TO PLAY AGAIN?
>n
R; T=4.73/9.44 13.30.46
>
```

APPENDIX B

INSTRUCTIONS ON USE OF PROGRAM SRCH2

The first data the program requires are the limits of the target area and types of boundaries. They must have the form

aawwwbbxxxccyyyddzzz

QUANTITY	MEANING	REQUIREMENTS
aa	West limit	$01<aa<25$
bb	East limit	$01<bb<25$; $bb>aa$
cc	North limit	$01<cc<25$
dd	South limit	$01<dd<25$; $dd>cc$
www	Type of the	
xxx	boundary which	REF for reflecting
yyy	preceeds each of	ABS for absorbing
zzz	these quantities	

Next, the program asks for the limits of the search area. The entry must have the form

aabbccdd

All quantities with the same meanings and fulfilling the same requirements as above.

Then, the program asks how many different values V_x can assume. Any positive integer less than 5 can be introduced, according to Format I2.

Use the same format to introduce the values of V_x, one per line.

The same question is made with respect to V_y, and the same instructions used for V_x apply.

Next, the transition matrix of V_x is to be introduced. Type

$\underline{ee}\,\underline{\ \ p\ \ }$

where $\underline{ee}$ is the value ΔV_x can assume with probability $\underline{\ p\ }$. Enter one line for each $\underline{\ p\ }$, after which, enter Ø. Summation of all $\underline{\ p\ }$ must be 1. $\underline{\ p\ }$ has the format F5.3.

The transition matrix for V_y is introduced in accordance with the same rules stated for V_x.

The last data before calculations begin is the a priori distribution of target, which must have the form

$\underline{ffgg}\,\underline{\ p\ }\ \underline{\ q_1\ }\ \underline{\ q_2\ }\ \ldots\ \underline{\ r_1\ }\ \underline{\ r_2\ }\ \ldots$

where $\underline{ff}$ and $\underline{gg}$ identify the cell where the target is with probability $\underline{\ p\ }$.

$\underline{\ q_1\ }\ \underline{\ q_2\ }$ ... are the conditional distribution of V_x, i.e., the probabilities of V_x being v_1^x, v_2^x, ... given the target is in cell (ff,gg). The number of quantities $\underline{\ q\ }$ must be equal to the number of possible values that V_x can assume. The summation of all $\underline{\ q\ }$ must be 1. The quantities $\underline{\ r\ }$ are the conditional distribution of V_y.

The format for quantities $\underline{\ p\ }$, $\underline{\ q\ }$ and $\underline{\ r\ }$ is F5.3.

Enter one line for each $\underline{\ p\ } \neq 0$, after which enter Ø.

Summation of all $\underline{\ p\ }$ must be one, too.

From this point on, all actions are repeated at each period.

The program prints a table similar to that in Fig. IV-2 which shows the coded distribution of the target at the beginning of the period, and then, asks for the total amount of effort available in the period and the detection rate.

Use format 2F5.3 to introduce these values.

In case the user does not want a myopic distribution, the effort is to be distributed as follows:

ffgg t

where ff and gg identify the cell where the amount t is placed.

Enter one line for each t $\neq$ 0.

Summation of all t must add up to the total amount of effort available in the period.

t has the format F10.8

Enter Ø after distributing the effort

Questions must be answered Yes (Y) or No (N) as in the following example:

```
>$ srch2
EXECUTION BEGINS...
 ENTER LIMITS OF TARGET AREA AND TYPES OF BOUNDARIES
>10ref15ref01ref25ref
 ENTER LIMITS OF SEARCH AREA
>01250125
 HOW MANY VALUES CAN V(X) ASSUME?
>03
 ENTER THESE VALUES, ONE PER LINE
>-1
>00
>01
 HOW MANY VALUES CAN V(Y) ASSUME?
>04
 ENTER THESE VALUES, ONE PER LINE
>-1
>00
>01
>02
```

```
 ENTER TRANSITION OF V(X)
>-10.3
>000.4
>010.3
>0
 ENTER TRANSITION OF V(Y)
>010.8
>020.2
>0
 ENTER A PRIORI DISTRIBUTIONS
>12120.3000.4000.3000.3000.1000.2000.3000.400
>12130.4000.5000.2000.3000.6000.2000.1000.100
>13140.3000.4000.4000.2000.5000.3000.1000.100
>0
 RANGE OF PROBABILITIES  0.30000      0.4000
     12
      23
      --
 12/ 0.
 13/ *.
 14/ .0
 ENTER TOTAL EFFORT AND DETECTION RATE
>1.0001.000
 MYOPIC PLAN?
>Y
 WANT TO KNOW DISTRIBUTION OF EFFORT?
>Y
   CELL    EFFORT
  12  12   0.2374
  12  13   0.5251
  13  14   0.2374
 AFTER 1 PERIODS, PROB DET IS 0.2902
 WANT TO CONTINUE?
> Y
 RANGE OF PROBABILITIES  0.66667#-02  0.12667
     11
      1234
      ----
  11/ 000.
  12/ *23.
  13/ 3671
  14/ 3440
  15/ 0000
  16/ .000
 ENTER TOTAL EFFORT AND DETECTION RATE
>1.0001.000
 MYOPIC PLAN?
>n
 ENTER DISTRIBUTION OF SEARCH EFFORT
>11120.7
>13130.3
>0
 AFTER 2 PERIODS, PROB DET IS 0.3569
 WANT TO CONTINUE
>n
 WANT TO PLAY AGAIN?
>n
R; &=7.10/8.93 14.06.39
```

PROGRAM SRCH1

```
      COMMON CELL(100,100),EF(100,100),PAT(60),
     2              MAP(60,2),LIM(4),NAT(4),
     3              MAXX,MINX,MAXY,MINY
      DIMENSION NIMB(4)
      DATA LAB,LIB,LOB/1HY,3HREF,3HABS/
  100 FORMAT (2X,'ENTER LIMITS OF TARGET AREA AND TYPE OF BOUNDARIES')
 1010 FORMAT (2X,'ENTER LIMITS OF SEARCH AREA')
 1011 FORMAT (4I3)
  101 FORMAT (4(I3,A3))
  102 FORMAT (2X,'ENTER TRANSITION MATRIX')
  103 FORMAT (2I3,2F10.8)
  104 FORMAT (2X,'INVALID INPUT DATA')
  105 FORMAT (2X,'ENTER A PRIORI DISTRIBUTION OF TARGET')
 1050 FORMAT (2X,'ENTER TOTAL EFFORT AND DETECTION RATE')
 1051 FORMAT (F5.3,F5.3)
 1052 FORMAT (2X,'MYOPIC PLAN?')
  106 FORMAT (2X,'ENTER DISTRIBUTION OF SEARCH EFFORT')
  108 FORMAT (2X,'WANT TO CONTINUE?')
  109 FORMAT (A1)
  111 FORMAT (21X,I2,4X,'(',I2,',',I2,')')
  112 FORMAT (2X,'WANT TO PLAY AGAIN?')
  120 WRITE (6,100)
  122 READ (5,101) ((LIM(I),NAT(I)),I=1,4)
      IF ((LIM(1).GE.1).AND.(LIM(2).LE.100).AND.
     2    (LIM(3).GE.1).AND.(LIM(4).LE.100))
     3     GO TO 1020
      WRITE (6,104)
      GO TO 120
 1020 WRITE (6,1010)
      READ (5,1011) (NIMB(J),J=1,4)
      IF ((NIMB(1).GE.1).AND.(NIMB(2).LE.100).AND.(NIMB(3).GE.1).
     2    AND.(NIMB(4).LE.100)) GO TO 123
      WRITE (6,104)
      GO TO 1020
  123 TOTAL=0.
      DO 124 I=1,60
      MAP(I,1)=0
      MAP(I,2)=0
      PAT(I)=0.
  124 CONTINUE
      IT=1
      WRITE (6,102)
  125 READ (5,103) MAP(IT,1),MAP(IT,2),PAT(IT)
      IF ((MAP(IT,1).EQ.0).AND.(MAP(IT,2).EQ.0).AND.
     2     (PAT(IT).EQ.0.)) GO TO 127
      TOTAL=TOTAL+PAT(IT)
      IT=IT+1
      IF (IT.LE.60) GO TO 125
```

```
127 IF (ABS(TOTAL-1.).LE.0.0001) GO TO 129
    WRITE (6,104)
    GO TO 123
129 CONTINUE
133 TOTAL=0.
    MAXX=0
    MINX=100
    MAXY=0
    MINY=100
    DO 137 I=1,100
    DO 137 J=1,100
    CELL(I,J)=0.
137 CONTINUE
    WRITE (6,105)
141 READ (5,103) N,M,CELL(M,N)
    IF ((N.EQ.0).AND.(M.EQ.0).AND.(CELL(M,N).EQ.0.)) GO TO 147
    MAXX=MAX0(MAXX,N)
    MINX=MIN0(MINX,N)
    MAXY=MAX0(MAXY,M)
    MINY=MIN0(MINY,M)
    TOTAL=TOTAL+CELL(M,N)
    GO TO 141
147 IF (ABS(TOTAL-1.).LE.0.0001) GO TO 149
    WRITE (6,104)
    GO TO 133
149 KOUNT=1
    PC=1.
155 CALL TABLE
    WRITE (6,1050)
    READ (5,1051) AM,FAC
    IF (FAC.LT.1.E-5) FAC=1.E-5
    WRITE (6,1052)
    READ (5,109) IANS
    IF (IANS.NE.LAB) GO TO 159
    CALL MYOPIC(AM,FAC,NIMB)
    GO TO 181
159 DO 160 I=1,100
    DO 160 J=1,100
    EF(I,J)=0.
160 CONTINUE
    TOTAL=0.
    WRITE (6,106)
163 READ (5,103) N,M,EF(M,N)
    IF ((N.EQ.0).AND.(M.EQ.0).AND.(EF(M,N).EQ.0.)) GO TO 171
    TOTAL=TOTAL+EF(M,N)
    GO TO 163
171 IF (ABS(TOTAL-AM).LE.1.E-03) GO TO 181
    WRITE (6,104)
```

```
      GO TO 159                                                         SEA00970
  181 CALL PROB (PG,KOUNT,FAC)                                          SEA00980
      WRITE (6,108)                                                     SEA00990
      READ (5,109) IANS                                                 SEA01000
      IF (IANS.NE.LAB) GO TO 189                                        SEA01010
      CALL UPDATE (LIB,LOB,IT,FAC)                                      SEA01020
      KOUNT=KOUNT+1                                                     SEA01030
      GO TO 155                                                         SEA01040
  189 WRITE (6,112)                                                     SEA01050
      READ (5,109) IANS                                                 SEA01060
      IF (IANS.NE.LAB) STOP                                             SEA01070
      GO TO 120                                                         SEA01080
      END                                                               SEA01090
```

```
      SUBROUTINE MYOPIC (A,FAC,NIMB)
      COMMON CELL(100,100),EF(100,100),FAT(60),
     2       MAP(6C,2),LIM(4),NAT(4),
     3       MAXX,MINX,MAXY,MINY
      DIMENSION ICELL(100,100),NIMB(4)
      DATA INDIA/1HY/
  101 FORMAT (2X,'WANT TO KNOW DISTRIBUTION OF EFFORT?')
  102 FORMAT (A1)
  103 FORMAT (2X,'  CELL    EFFORT  ')
  104 FORMAT (2X,I3,1X,I3,2X,F6.4)
  200 DO 201 I=MINY,MAXY
      DO 201 J=MINX,MAXX
      ICELL(I,J)=0
  201 CONTINUE
  226 DO 231 I=MINY,MAXY
      DO 231 J=MINX,MAXX
      EF(I,J)=0.
  231 CONTINUE
  241 IMIN=0
      JMIN=0
      B=1.
      N=0
      PMIN=1.
      IFLAG=0
      DO 247 I=MINY,MAXY
      DO 247 J=MINX,MAXX
      IF ((CELL(I,J).EQ.0.).OR.(ICELL(I,J).EQ.1).OR.(I.LT.NIMB(3)).OR.
     2   (I.GT.NIMB(4)).OR.(J.LT.NIMB(1)).OR.(J.GT.NIMB(2)))
     3 GO TO 247
      IF ((CELL(I,J).GE.PMIN).OR.(IFLAG.EQ.1))GO TO 243
      PMIN=CELL(I,J)
      IMIN=I
      JMIN=J
  243 CONTINUE
      IF ((CELL(I,J).LE.PMIN).AND.(IFLAG.EQ.1)) ICELL(I,J)=1
      IF (IFLAG.EQ.1) GO TO 247
      N=N+1
      B=(B**(1./(FAC*FLOAT(N))))**((FAC*FLOAT(N-1)))
      B=B*CELL(I,J)**(1./(FAC*FLOAT(N)))
      REF=EXP(A/FLOAT(N))
      BEF=B/(PMIN**(1./FAC))
      IF (REF.GE.BEF) GO TO 247
      ICELL(IMIN,JMIN)=1
      IFLAG=1
  247 CONTINUE
      IF (IFLAG.EQ.0) GO TO 248
      GO TO 241
  248 DO 251 I=MINY,MAXY
```

```
      DO 251 J=MINX,MAXX                                                 SEA01580
      IF ((CELL(I,J).EQ.0.).OR.(ICELL(I,J).NE.0).OR.                    SEA01590
     2    (I.LT.NIMB(3)).OR.(I.GT.NIMB(4)).OR.(J.LT.NIMB(1)).OR.         SEA01600
     3    (J.GT.NIMB(2))) GO TO 251                                      SEA01610
      FFCB=B**(FAC*FLOAT(N))                                             SEA01620
      EF(I,J)=(ALOG(CELL(I,J))/FAC)+(A/FLOAT(N))-                        SEA01630
     2         (ALOG(PROB)/(FAC*FLOAT(N)))                               SEA01640
  251 CONTINUE                                                           SEA01650
      WRITE (6,101)                                                      SEA01660
      READ (5,102) IPU                                                   SEA01670
      IF (IPU.NE.INDIA) RETURN                                           SEA01680
      WRITE (6,103)                                                      SEA01690
      DO 281 I=MINY,MAXY                                                 SEA01700
      DO 281 J=MINX,MAXX                                                 SEA01710
      IF (EF(I,J).EQ.0.) GO TO 281                                       SEA01720
      WRITE (6,104) J,I,EF(I,J)                                          SEA01730
  281 CONTINUE                                                           SEA01740
      RETURN                                                             SEA01750
      END                                                                SEA01760
```

```
      SUBROUTINE TABLE                                                  SEA01770
      COMMON CELL(100,100),EF(100,100),PAT(60),                         SEA01780
     2               MAP(60,2),LIM(4),NAT(4),                           SEA01790
     3               MAXX,MINX,MAXY,MINY                                SEA01800
      DIMENSION ICELL(100),IMBOL(15)                                    SEA01810
      DATA IMBOL/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,                       SEA01820
     2           1H8,1H9,1H*,1H.,1H-,1H /                               SEA01830
  100 FORMAT (2X,'RANGE OF PROBABILITIES',2(1X,G12.5))                  SEA01840
  101 FORMAT (2X,I3,'/ ',100A1)                                         SEA01850
  102 FORMAT (6X,I2,9(8X,I2))                                           SEA01860
  103 FORMAT (7X,100I1)                                                 SEA01870
  104 FORMAT (7X,100A1)                                                 SEA01880
      SMALL=1.                                                          SEA01890
      BIG=0.                                                            SEA01900
      DO 217 I=MINY,MAXY                                                SEA01910
      DO 217 J=MINX,MAXX                                                SEA01920
      IF ((CELL(I,J).NE.0.).AND.(CELL(I,J).LT.SMALL)) SMALL=CELL(I,J)   SEA01930
      IF (CELL(I,J).GT.BIG) BIG=CELL(I,J)                               SEA01940
  217 CONTINUE                                                          SEA01950
      WRITE (6,100) SMALL,BIG                                           SEA01960
      IF ((BIG-SMALL).LT.1.E-10) SMALL=0.                               SEA01970
      DO 417 I=1,100                                                    SEA01980
      ICELL(I)=MINX+(I-1)*10                                            SEA01990
      IF (ICELL(I).GT.MAXX) GO TO 418                                   SEA02000
  417 CONTINUE                                                          SEA02010
  418 I=I-1                                                             SEA02020
      WRITE (6,102) (ICELL(J),J=1,I)                                    SEA02030
      LA=MAXX-MINX+1                                                    SEA02040
      DO 517 N=1,LA                                                     SEA02050
      ICELL(N)=MOD(N-1+MINX,10)                                         SEA02060
  517 CONTINUE                                                          SEA02070
      WRITE (6,103) (ICELL(I),I=1,LA)                                   SEA02080
      DO 617 I=1,LA                                                     SEA02090
      ICELL(I)=IMBOL(13)                                                SEA02100
  617 CONTINUE                                                          SEA02110
      WRITE (6,104) (ICELL(I),I=1,LA)                                   SEA02120
      DO 817 I=MINY,MAXY                                                SEA02130
      DO 717 J=MINX,MAXX                                                SEA02140
       ICELL(J)=IMBOL(1+IFIX(10.                                        SEA02150
     2  -SQRT(100.-(CELL(I,J)-SMALL)/(BIG-SMALL)*100.)))                SEA02160
      IF (CELL(I,J).EQ.0.) ICELL(J)=IMBOL(12)                           SEA02170
  717 CONTINUE                                                          SEA02180
      WRITE (6,101) I,(ICELL(J),J=MINX,MAXX)                            SEA02190
  817 CONTINUE                                                          SEA02200
      RETURN                                                            SEA02210
      END                                                               SEA02220
```

```
      SUBROUTINE UPDATE (LIB,LOB,IT,FAC)                                SEA02230
      COMMON CELL(100,100),EF(100,100),PAT(60),                         SEA02240
     2                MAP(60,2),LIM(4),NAT(4),                          SEA02250
     3                MAXX,MINX,MAXY,MINY                               SEA02260
      DENOM=0.                                                          SEA02270
      DO 318 I=1,100                                                    SEA02280
      DO 318 J=1,100                                                    SEA02290
      DENOM=DENOM+CELL(I,J)*EXP(-FAC*EF(I,J))                           SEA02300
  318 CONTINUE                                                          SEA02310
      DO 319 I=1,100                                                    SEA02320
      DO 319 J=1,100                                                    SEA02330
      CELL(I,J)=CELL(I,J)*EXP(-FAC*EF(I,J))/DENOM                       SEA02340
      EF(I,J)=0.                                                        SEA02350
  319 CONTINUE                                                          SEA02360
      CALL SPREAD (LIB,LOB,IT)                                          SEA02370
      RETURN                                                            SEA02380
      END                                                               SEA02390
```

```
      SUBROUTINE SPREAD (LIB,LOB,IT)                                    SEA02400
      COMMON CELL(100,100),EF(100,100),PAT(60),                         SEA02410
     2               MAP(60,2),LIM(4),NAT(4),                           SEA02420
     3               MAXX,MINX,MAXY,MINY                                SEA02430
      MAXX=0                                                            SEA02440
      MINX=100                                                          SEA02450
      MAXY=0                                                            SEA02460
      MINY=100                                                          SEA02470
      DO 419 I=1,100                                                    SEA02480
      DO 419 J=1,100                                                    SEA02490
      IF (CELL(J,I).EQ.0.) GO TO 419                                    SEA02500
      DO 418 N=1,IT                                                     SEA02510
      LI=I+MAP(N,1)                                                     SEA02520
      LJ=J+MAP(N,2)                                                     SEA02530
      IF (((I.LT.LIM(1)).AND.(LI.GE.LIM(1)).AND.(NAT(1).EQ.LOB)).OR.    SEA02540
     2    ((I.GT.LIM(2)).AND.(LI.LE.LIM(2)).AND.(NAT(2).EQ.LOB)).OR.    SEA02550
     3    (((LIM(1).LE.I).AND.(LIM(2).GE.I)).AND.                       SEA02560
     4    (((LI.LT.LIM(1)).AND.(NAT(1).EQ.LIB)).OR.                     SEA02570
     5    ((LI.GT.LIM(2)).AND.(NAT(2).EQ.LIB)))))                       SEA02580
     6            LI=I-MAP(N,1)                                         SEA02590
      IF (((J.LT.LIM(3)).AND.(LJ.GE.LIM(3)).AND.(NAT(3).EQ.LOB)).OR.    SEA02600
     2    ((J.GT.LIM(4)).AND.(LJ.LE.LIM(4)).AND.(NAT(4).EQ.LOB)).OR.    SEA02610
     3    (((LIM(3).LE.J).AND.(LIM(4).GE.J)).AND.                       SEA02620
     4    (((LJ.LT.LIM(3)).AND.(NAT(3).EQ.LIB)).OR.                     SEA02630
     5    ((LJ.GT.LIM(4)).AND.(NAT(4).EQ.LIB)))))                       SEA02640
     6            LJ=J-MAP(N,2)                                         SEA02650
      IF ((LI.LT.1).OR.(LI.GT.100).OR.(LJ.LT.1).OR.(LJ.GT.100))         SEA02660
     2   GO TO 418                                                      SEA02670
      EF (LJ,LI)=EF(LJ,LI)+PAT(N)*CELL(J,I)                             SEA02680
  418 CONTINUE                                                          SEA02690
  419 CONTINUE                                                          SEA02700
      DO 518 I=1,100                                                    SEA02710
      DO 518 J=1,100                                                    SEA02720
      CELL(I,J)=EF(I,J)                                                 SEA02730
      IF (CELL(I,J).EQ.0.) GO TO 518                                    SEA02740
      MAXX=MAX0(MAXX,J)                                                 SEA02750
      MINX=MIN0(MINX,J)                                                 SEA02760
      MAXY=MAX0(MAXY,I)                                                 SEA02770
      MINY=MIN0(MINY,I)                                                 SEA02780
  518 CONTINUE                                                          SEA02790
      RETURN                                                            SEA02800
      END                                                               SEA02810
```

```
      SUBROUTINE PROB(PG,KOUNT,FAC)                                      SEA02820
      COMMON CELL(100,100),EF(100,100),PAT(60),                          SEA02830
     2               MAP(60,2),LIM(4),NAT(4),                            SEA02840
     3               MAXX,MINX,MAXY,MINY                                 SEA02850
  100 FORMAT (2X,'AFTER',1X,I2,1X,'PERIODS, PROB DET IS ',G12.5)         SEA02860
      PNOT=0.                                                            SEA02870
      DO 517 I=MINY,MAXY                                                 SEA02880
      DO 517 J=MINX,MAXX                                                 SEA02890
      PNOT=PNOT+CELL(I,J)*(1.-EXP(-FAC*EF(I,J)))                         SEA02900
  517 CONTINUE                                                           SEA02910
      PNOT=1.-PNOT                                                       SEA02920
      PG=PG*PNOT                                                         SEA02930
      PNOT=1.-PG                                                         SEA02940
      WRITE (6,100) KOUNT,PNOT                                           SEA02950
      RETURN                                                             SEA02960
      END                                                                SEA02970
```

PROGRAM SRCH2

```
      COMMON CELL(25,25,4,4),EF(25,25),PDSX(10),PDSY(10),                 SEC00010
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),              SEC00020
     3       MAXX,MINX,MAXY,MINY                                          SEC00030
      DIMENSION NIMB(4)                                                   SEC00040
      DATA LAB,LIB,LOB/1HY,3HREF,3HABS/                                   SEC00050
   90 FORMAT (2X,'ENTER LIMITS OF TARGET AREA AND TYPES OF BOUNDARIES')  SEC00060
   91 FORMAT (4(I2,A3))                                                   SEC00070
  100 FORMAT (2X,'ENTER LIMITS OF SEARCH AREA')                           SEC00080
 1000 FORMAT (4I2)                                                        SEC00090
  101 FORMAT (2X,'HOW MANY VALUES CAN V(X) ASSUME?')                      SEC00100
  102 FORMAT (2X,'INVALID INPUT DATA')                                    SEC00110
  103 FORMAT (2X,'HOW MANY VALUES CAN V(Y) ASSUME?')                      SEC00120
  104 FORMAT (2X,'ENTER THESE VALUES, ONE PER LINE')                      SEC00130
  105 FORMAT (2X,'ENTER TRANSITION OF V(X)')                              SEC00140
  106 FORMAT (I2,F5.3)                                                    SEC00150
  107 FORMAT (2X,'ENTER TRANSITION OF V(Y)')                              SEC00160
  108 FORMAT (2X,'ENTER A PRIORI DISTRIBUTIONS')                          SEC00170
  109 FORMAT (2I2,11F5.3)                                                 SEC00180
 1090 FORMAT (2X,'ENTER TOTAL EFFORT AND DETECTION RATE')                 SEC00190
 1091 FORMAT (2F5.3)                                                      SEC00200
 1092 FORMAT (2X,'MYOPIC PLAN?')                                          SEC00210
  110 FORMAT (2X,'ENTER DISTRIBUTION OF SEARCH EFFORT')                   SEC00220
  112 FORMAT (2X,'WANT TO CONTINUE?')                                     SEC00230
  113 FORMAT (2X,'REPEAT LAST ENTRY')                                     SEC00240
  114 FORMAT (2X,'WANT TO PLAY AGAIN?')                                   SEC00250
  115 FORMAT (A1)                                                         SEC00260
  180 WRITE (6,90)                                                        SEC00270
      READ (5,91) ((LIM(I),NAT(I)),I=1,4)                                 SEC00280
      IF ((LIM(1).GE.1).AND.(LIM(2).LE.25).AND.(LIM(3).GE.1).             SEC00290
     2    AND.(LIM(4).LE.25)) GO TO 189                                   SEC00300
      WRITE (6,102)                                                       SEC00310
      GO TO 180                                                           SEC00320
  189 WRITE (6,100)                                                       SEC00330
      READ (5,1000) (NIMB(J),J=1,4)                                       SEC00340
      IF ((NIMB(1).GE.1).AND.(NIMB(2).LE.25).AND.(NIMB(3).                SEC00350
     2     GE.1).AND.(NIMB(4).LE.25)) GO TO 200                           SEC00360
      WRITE (6,102)                                                       SEC00370
      GO TO 189                                                           SEC00380
  200 MAXSX=-1000                                                         SEC00390
      MINSX=1000                                                          SEC00400
      MAXSY=-1000                                                         SEC00410
      MINSY=1000                                                          SEC00420
  201 WRITE (6,101)                                                       SEC00430
      READ (5,106) IX                                                     SEC00440
      IF (IX.LE.4) GO TO 202                                              SEC00450
      WRITE (6,102)                                                       SEC00460
      GO TO 201                                                           SEC00470
  202 WRITE (6,104)                                                       SEC00480
```

```
      DO 203 I=1,IX
      READ (5,106) NSX(I)
      MAXSX=MAX0(MAXSX,NSX(I))
      MINSX=MIN0(MINSX,NSX(I))
  203 CONTINUE
  204 WRITE (6,103)
      READ (5,106) IY
      IF (IY.LE.4) GO TO 205
      WRITE (6,102)
      GO TO 204
  205 WRITE (6,104)
      DO 206 I=1,IY
      READ (5,106) NSY(I)
      MAXSY=MAX0(MAXSY,NSY(I))
      MINSY=MIN0(MINSY,NSY(I))
  206 CONTINUE
  209 WRITE (6,105)
      DO 208 I=1,10
      IDSX(I)=0
      PDSX(I)=0.
  208 CONTINUE
      EF(17,19)=0.
      INX=1
  211 READ (5,106) IDSX(INX),PDSX(INX)
      IF ((IDSX(INX).EQ.0).AND.(PDSX(INX).EQ.0.)) GO TO 219
      EF(17,19)=EF(17,19)+PDSX(INX)
      INX=INX+1
      IF (INX.LE.10) GO TO 211
  219 IF (ABS(EF(17,19)-1.).LE.1.E-04) GO TO 235
      WRITE (6,102)
      GO TO 209
  235 WRITE (6,107)
      INX=INX-1
      DO 236 I=1,10
      IDSY(I)=0
      PDSY(I)=0.
  236 CONTINUE
      EF(21,25)=0.
      INY=1
  237 READ (5,106) IDSY(INY),PDSY(INY)
      IF ((IDSY(INY).EQ.0).AND.(PDSY(INY).EQ.0.)) GO TO 239
      EF(21,25)=EF(21,25)+PDSY(INY)
      INY=INY+1
      IF (INY.LE.10) GO TO 237
  239 IF (ABS(EF(21,25)-1.).LE.1.E-04) GO TO 253
      WRITE (6,102)
      GO TO 235
  253 EF(3,3)=0.
```

```
      INY=INY-1
      DO 2660 I=1,25
      DO 2660 J=1,25
      DO 2660 K=1,4
      DO 2660 L=1,4
      CELL(I,J,K,L)=0.
 2660 CONTINUE
      EF(20,20)=0.
      MAXX=0
      MINX=100
      MAXY=0
      MINY=100
      WRITE (6,108)
  254 EF(3,3)=EF(3,3)+EF(20,20)
      READ (5,109) I,J,EF(20,20),(EF(1,K),K=1,IX),(EF(2,L),L=1,IY)
      IF ((I.EQ.0).AND.(J.EQ.0).AND.(EF(20,20).EQ.0.)) GO TO 262
      EF(5,2)=0.
      DO 259 M=1,IY
      EF(5,2)=EF(5,2)+EF(2,M)
      EF(5,1)=0.
      DO 259 N=1,IX
      EF(5,1)=EF(5,1)+EF(1,N)
      CELL(J,I,M,N)=EF(20,20)*EF(2,M)*EF(1,N)
  259 CONTINUE
      IF ((ABS(EF(5,1)-1.).GT.1.0E-04).OR.
     2    (ABS(EF(5,2)-1.).GT.1.0E-04)) GO TO 260
      MAXX=MAX0(MAXX,I)
      MINX=MIN0(MINX,I)
      MAXY=MAX0(MAXY,J)
      MINY=MIN0(MINY,J)
      GO TO 254
  260 EF(20,20)=0.
      DO 261 M=1,4
      EF(1,M)=0.
      EF(2,M)=0.
      DO 261 N=1,4
      CELL(I,J,M,N)=0.
  261 CONTINUE
      WRITE (6,102)
      WRITE (6,113)
      GO TO 254
  262 IF (ABS(EF(3,3)-1.).LE.1.0E-04) GO TO 264
      DO 263 I=1,25
      DO 263 J=1,25
      DO 263 K=1,4
      DO 263 L=1,4
      CELL(I,J,K,L)=0.
  263 CONTINUE
```

```
      WRITE (6,102)                                                     SEC01450
      GO TO 253                                                         SEC01460
  264 KOUNT=1                                                           SEC01470
      PG=1.                                                             SEC01480
  265 CALL TABLE (IX,IY)                                                SEC01490
      WRITE (6,1090)                                                    SEC01500
      READ (5,1091) A,FAC                                               SEC01510
      IF (FAC.LT.1.E-05) FAC=1.E-05                                     SEC01520
      WRITE (6,1092)                                                    SEC01530
      READ (5,115) IANS                                                 SEC01540
      IF (IANS.NE.LAB) GO TO 2067                                       SEC01550
      CALL MYOPIC (A,FAC,IX,IY,NIMB)                                    SEC01560
      GO TO 281                                                         SEC01570
 2067 TOT=0.                                                            SEC01580
      DO 266 I=1,25                                                     SEC01590
      DO 266 J=1,25                                                     SEC01600
      EF(I,J)=0.                                                        SEC01610
  266 CONTINUE                                                          SEC01620
      WRITE (6,110)                                                     SEC01630
  267 READ (5,109) I,J,EF(J,I)                                          SEC01640
      IF ((I.EQ.0).AND.(J.EQ.0).AND.(EF(J,I).EQ.0.)) GO TO 269          SEC01650
      TOT=TOT+EF(J,I)                                                   SEC01660
      EF(J,I)=EF(J,I)*FAC                                               SEC01670
      GO TO 267                                                         SEC01680
  269 IF (ABS(TOT-A).LE.1.E-03) GO TO 281                               SEC01690
      WRITE (6,102)                                                     SEC01700
      GO TO 2067                                                        SEC01710
  281 CALL PROB (PG,KOUNT,IX,IY)                                        SEC01720
      WRITE (6,112)                                                     SEC01730
      READ (5,115) IANS                                                 SEC01740
      IF (IANS.NE.LAB) GO TO 283                                        SEC01750
      CALL UPDATE (IX,IY,INX,INY,MAXSX,MINSX,MAXSY,MINSY,LIB,LCB)       SEC01760
      KOUNT=KOUNT+1                                                     SEC01770
      GO TO 265                                                         SEC01780
  283 WRITE (6,114)                                                     SEC01790
      READ (5,115) IANS                                                 SEC01800
      IF (IANS.NE.LAB) STOP                                             SEC01810
      GO TO 180                                                         SEC01820
      END                                                               SEC01830
```

```
      SUBROUTINE MYOPIC (A,FAC,IX,IY,NIMB)                              SEC01840
      COMMON CELL(25,25,4,4),EF(25,25),PCSX(10),PCSY(10),               SEC01850
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),             SEC01860
     3       MAXX,MINX,MAXY,MINY                                        SEC01870
      DIMENSION TCELL(25,25),ICELL(25,25),NIMB(4)                       SEC01880
      DATA INDIA/1HY/                                                   SEC01890
  101 FORMAT (2X,'WANT TO KNOW DISTRIBUTION OF EFFORT?')                SEC01900
  102 FORMAT (A1)                                                       SEC01910
  103 FORMAT (2X,'  CELL     EFFORT')                                   SEC01920
  104 FORMAT (2X,I3,1X,I3,3X,F6.4)                                      SEC01930
   99 DO 190 I=MINY,MAXY                                                SEC01940
      DO 190 J=MINX,MAXX                                                SEC01950
      TCELL(I,J)=0.                                                     SEC01960
      DO 190 K=1,IY                                                     SEC01970
      DO 190 L=1,IX                                                     SEC01980
      TCELL(I,J)=TCELL(I,J)+CELL(I,J,K,L)                               SEC01990
  190 CONTINUE                                                          SEC02000
  200 DO 201 I=MINY,MAXY                                                SEC02010
      DO 201 J=MINX,MAXX                                                SEC02020
      ICELL(I,J)=0                                                      SEC02030
  201 CONTINUE                                                          SEC02040
  226 DO 231 I=1,25                                                     SEC02050
      DO 231 J=1,25                                                     SEC02060
      EF(I,J)=0.                                                        SEC02070
  231 CONTINUE                                                          SEC02080
  241 IMIN=0                                                            SEC02090
      JMIN=0                                                            SEC02100
      B=1.                                                              SEC02110
      N=0                                                               SEC02120
      PMIN=1.                                                           SEC02130
      IFLAG=0                                                           SEC02140
      DO 247 I=MINY,MAXY                                                SEC02150
      DO 247 J=MINX,MAXX                                                SEC02160
      IF ((TCELL(I,J).EQ.0.).OR.(ICELL(I,J).EQ.1).OR.(I.LT.NIMB(3))     SEC02170
     2   .OR.(I.GT.NIMB(4)).OR.(J.LT.NIMB(1)).OR.(J.GT.NIMB(2)))        SEC02180
     3   GO TO 247                                                      SEC02190
      IF ((TCELL(I,J).GE.PMIN).OR.(IFLAG.EQ.1)) GO TO 243               SEC02200
      PMIN=TCELL(I,J)                                                   SEC02210
      IMIN=I                                                            SEC02220
      JMIN=J                                                            SEC02230
  243 CONTINUE                                                          SEC02240
      IF ((TCELL(I,J).LE.PMIN).AND.(IFLAG.EQ.1)) ICELL(I,J)=1           SEC02250
      IF (IFLAG.EQ.1) GO TO 247                                         SEC02260
      N=N+1                                                             SEC02270
      B=(B**(1./(FAC*FLOAT(N))))**((FAC*FLOAT(N-1)))                    SEC02280
      B=B*TCELL(I,J)**(1./(FAC*FLOAT(N)))                               SEC02290
      REF=EXP(A/FLOAT(N))                                               SEC02300
      BEF=B/(PMIN**(1./FAC))                                            SEC02310
```

```
      IF (REF.GE.BEF) GC TO 247                                         SEC02320
      ICELL(IMIN,JMIN)=1                                                SEC02330
      IFLAG=1                                                           SEC02340
  247 CCNTINUE                                                          SEC02350
      IF (IFLAG.EG.0) GO TO 248                                         SEC02360
      GC TO 241                                                         SEC02370
  248 DC 251 I=MINY,MAXY                                                SEC02380
      DC 251 J=MINX,MAXX                                                SEC02390
      IF ((TCELL(I,J).EQ.0.).OR.(ICELL(I,J).EQ.1).OR.(I.LT.NIMB(3)).    SEC02400
     2    OR.(I.GT.NIMB(4)).OR.(J.LT.NIMB(1)).OR.(J.GT.NIMB(2)))        SEC02410
     3     GO TO 251                                                    SEC02420
      PROB=B**(FAC*FLOAT(N))                                            SEC02430
      EF(I,J)=(ALOG(TCELL(I,J))/FAC)+(A/FLOAT(N))-                      SEC02440
     2        (ALCG(PROB)/(FAC*FLOAT(N)))                               SEC02450
  251 CONTINUE                                                          SEC02460
      WRITE (6,101)                                                     SEC02470
      READ (5,102) IPU                                                  SEC02480
      IF (IPU.NE.INDIA) RETURN                                          SEC02490
      WRITE (6,103)                                                     SEC02500
      DC 281 I=MINY,MAXY                                                SEC02510
      DC 281 J=MINX,MAXX                                                SEC02520
      IF (EF(I,J).EQ.0.) GO TO 281                                      SEC02530
      WRITE (6,104) J,I,EF(I,J)                                         SEC02540
  281 CONTINUE                                                          SEC02550
      RETURN                                                            SEC02560
      END                                                               SEC02570
```

```
      SUBROUTINE TABLE (IX,IY)
      COMMON CELL(25,25,4,4),EF(25,25),PDSX(10),PDSY(10),
     2          NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),
     3          MAXX,MINX,MAXY,MINY
      DIMENSION ICELL(25),IMBOL(15)
      DATA IMBOL/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,
     2          1H*,1H.,1H-,1HY/
  100 FORMAT (2X,'RANGE OF PROBABILITIES',2(1X,G12.5))
  101 FORMAT (2X,I3,'/ ',100A1)
  102 FORMAT (6X,I2,9(8X,I2))
  103 FORMAT (7X,100I1)
  104 FORMAT (7X,100A1)
      DO 201 I=1,25
      DO 201 J=1,25
      EF(I,J)=0.
      DO 201 K=1,IY
      DO 201 L=1,IX
      EF(I,J)=EF(I,J)+CELL(I,J,K,L)
  201 CONTINUE
      SMALL=1.
      BIG=0.
      DO 217 I=MINY,MAXY
      DO 217 J=MINX,MAXX
      IF ((EF(I,J).NE.0.).AND.(EF(I,J).LT.SMALL)) SMALL=EF(I,J)
      IF (EF(I,J).GT.BIG) BIG=EF(I,J)
  217 CONTINUE
      WRITE (6,100) SMALL,BIG
      IF ((BIG-SMALL).LT.1.E-5) SMALL=0.
      DO 417 I=1,25
      ICELL(I)=MINX+(I-1)*10
      IF (ICELL(I).GT.MAXX) GO TO 418
  417 CONTINUE
  418 I=I-1
      WRITE (6,102) (ICELL(J),J=1,I)
      LA=MAXX-MINX+1
      DO 517 N=1,LA
      ICELL(N)=MOD(N-1+MINX,10)
  517 CONTINUE
      WRITE (6,103) (ICELL(I),I=1,LA)
      DO 617 I=1,LA
      ICELL(I)=IMBOL(13)
  617 CONTINUE
      WRITE (6,104) (ICELL(I),I=1,LA)
      DO 817 I=MINY,MAXY
      DO 717 J=MINX,MAXX
       ICELL(J)=IMBOL(1.+
     2   IFIX(10.-SQRT(100.-(EF(I,J)-SMALL)/(BIG-SMALL)*100.)))
      IF (EF(I,J).EQ.0.) ICELL(J)=IMBOL(12)
```

```
717 CCNTINUE
    WRITE (6,101) I,(ICELL(J),J=MINX,MAXX)
817 CCNTINUE
    RETURN
    END
```

```
      SUBROUTINE PROB (PG,KOUNT,IX,IY)                                  SEC03110
      COMMON CELL(25,25,4,4),EF(25,25),PDSX(10),PDSY(10),               SEC03120
     2       .NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),            SEC03130
     3        MAXX,MINX,MAXY,MINY                                       SEC03140
  101 FORMAT (2X,'AFTER',1X,I2,1X,'PERIODS, PROB DET IS ',F6.4)         SEC03150
      PNOT=1.                                                           SEC03160
      DO 219 I=1,25                                                     SEC03170
      DO 219 J=1,25                                                     SEC03180
      A=0.                                                              SEC03190
      DO 217 K=1,IY                                                     SEC03200
      DO 217 L=1,IX                                                     SEC03210
      A=A+CELL(I,J,K,L)                                                 SEC03220
  217 CONTINUE                                                          SEC03230
      PNOT=PNOT-A*(1.-EXP(-EF(I,J)))                                    SEC03240
  219 CONTINUE                                                          SEC03250
      PG=PG*PNOT                                                        SEC03260
      PNOT=1.-PG                                                        SEC03270
      WRITE (6,101) KOUNT,PNOT                                          SEC03280
      RETURN                                                            SEC03290
      END                                                               SEC03300
```

```
      SUBROUTINE UPDATE (IX,IY,INX,INY,MAXSX,MINSX,MAXSY,MINSY,         SEC03310
     2                   LIB,LOB)                                        SEC03320
      COMMON CELL(25,25,4,4),EF(25,25),PCSX(10),PCSY(10),                SEC03330
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),              SEC03340
     3       MAXX,MINX,MAXY,MINY                                         SEC03350
      DIMENSION TCELL(25,25),PVY(10),PVX(10)                             SEC03360
      DENOM=0.                                                           SEC03370
      DO 319 I=1,25                                                      SEC03380
      DO 319 J=1,25                                                      SEC03390
      TCELL(I,J)=0.                                                      SEC03400
      DO 318 K=1,IY                                                      SEC03410
      DO 318 L=1,IX                                                      SEC03420
      TCELL(I,J)=TCELL(I,J)+CELL(I,J,K,L)                                SEC03430
  318 CONTINUE                                                           SEC03440
      DENOM=DENOM+TCELL(I,J)*EXP(-EF(I,J))                               SEC03450
  319 CONTINUE                                                           SEC03460
      DO 351 I=1,25                                                      SEC03470
      DO 351 J=1,25                                                      SEC03480
      DO 339 L=1,IX                                                      SEC03490
      PVX(L)=0.                                                          SEC03500
      DO 338 K=1,IY                                                      SEC03510
      PVX(L)=PVX(L)+CELL(I,J,K,L)                                        SEC03520
  338 CONTINUE                                                           SEC03530
      IF (TCELL(I,J).EQ.0.) GO TO 339                                    SEC03540
      PVX(L)=PVX(L)/TCELL(I,J)                                           SEC03550
  339 CONTINUE                                                           SEC03560
      DO 345 K=1,IY                                                      SEC03570
      PVY(K)=0.                                                          SEC03580
      DO 341 L=1,IX                                                      SEC03590
      PVY(K)=PVY(K)+CELL(I,J,K,L)                                        SEC03600
  341 CONTINUE                                                           SEC03610
      IF (TCELL(I,J).EQ.0.) GO TO 345                                    SEC03620
      PVY(K)=PVY(K)/TCELL(I,J)                                           SEC03630
  345 CONTINUE                                                           SEC03640
      TCELL(I,J)=TCELL(I,J)*EXP(-EF(I,J))/DENOM                          SEC03650
      DO 347 K=1,IY                                                      SEC03660
      DO 347 L=1,IX                                                      SEC03670
      CELL(I,J,K,L)=TCELL(I,J)*PVY(K)*PVX(L)                             SEC03680
  347 CONTINUE                                                           SEC03690
  351 CONTINUE                                                           SEC03700
      CALL SPREAD (IX,IY,INX,INY,MAXSX,MINSX,MAXSY,MINSY,LIB,LOB)        SEC03710
      RETURN                                                             SEC03720
      END                                                                SEC03730
```

```
      SUBROUTINE SPREAD (IX,IY,INX,INY,MAXSX,MINSX,MAXSY,MINSY,
     2                   LIB,LOB)
      COMMON CELL(25,25,4,4),EF(25,25),PCSX(10),PCSY(10),
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),
     3       MAXX,MINX,MAXY,MINY
      DIMENSION TCELL(25,25,4,4),INAX(10,4),INAY(10,4)
      DO 201 I=1,25
      DO 201 J=1,25
      DO 201 K=1,IY
      DO 201 L=1,IX
      TCELL(I,J,K,L)=0.
  201 CONTINUE
      DO 231 I=1,25
      DO 231 J=1,25
      DO 231 K=1,IY
      DO 231 L=1,IX
      LI=I+NSX(L)
      LJ=J+NSY(K)
      IF (((I.LT.LIM(1)).AND.(LI.GE.LIM(1)).AND.(NAT(1).EQ.LOB)).OR.
     2    ((I.GT.LIM(2)).AND.(LI.LE.LIM(2)).AND.(NAT(2).EQ.LOB)).OR.
     3    (((LIM(1).LE.I).AND.(LIM(2).GE.I)).AND.
     4    (((LI.LT.LIM(1)).AND.(NAT(1).EQ.LIB)).OR.
     5    ((LI.GT.LIM(2)).AND.(NAT(2).EQ.LIB)))))
     6        LI=I-NSX(L)
      IF (((J.LT.LIM(3)).AND.(LJ.GE.LIM(3)).AND.(NAT(3).EQ.LOB)).OR.
     2    ((J.GT.LIM(4)).AND.(LJ.LE.LIM(4)).AND.(NAT(4).EQ.LOB)).OR.
     3    (((LIM(3).LE.J).AND.(LIM(4).GE.J)).AND.
     4    (((LJ.LT.LIM(3)).AND.(NAT(3).EQ.LIB)).OR.
     5    ((LJ.GT.LIM(4)).AND.(NAT(4).EQ.LIB)))))
     6       LJ=J-NSY(K)
      IF ((LI.LT.1).OR.(LJ.LT.1).OR.
     2    (LI.GT.25).OR.(LJ.GT.25)) GO TO 231
      TCELL(LJ,LI,K,L)=TCELL(LJ,LI,K,L)+CELL(J,I,K,L)
  231 CONTINUE
      MAXX=0
      MINX=30
      MAXY=0
      MINY=30
      DO 251 I=1,25
      DO 251 J=1,25
      DO 251 K=1,IY
      DO 251 L=1,IX
      IF (TCELL(I,J,K,L).EQ.0.) GO TO 249
      MAXX=MAX0(MAXX,J)
      MINX=MIN0(MINX,J)
      MAXY=MAX0(MAXY,I)
      MINY=MIN0(MINY,I)
  249 CELL(I,J,K,L)=0.
```

```
251 CONTINUE                                                            SEC04220
    DO 701 I=1,INX                                                      SEC04230
    DO 701 J=1,IX                                                       SEC04240
    INAX(I,J)=MAXO(MINSX,MINO(MAXSX,NSX(J)+IDSX(I)))                    SEC04250
701 CONTINUE                                                            SEC04260
    DO 702 I=1,INY                                                      SEC04270
    DO 702 J=1,IY                                                       SEC04280
    INAY(I,J)=MAXO(MINSY,MINO(MAXSY,NSY(J)+IDSY(I)))                    SEC04290
702 CONTINUE                                                            SEC04300
    DO 710 I=MINY,MAXY                                                  SEC04310
    DO 710 J=MINX,MAXX                                                  SEC04320
    DO 710 IINX=1,INX                                                   SEC04330
    DO 710 IIX=1,IX                                                     SEC04340
    DO 705 N=1,IX                                                       SEC04350
    IF (INAX(IINX,IIX).EQ.NSX(N)) GO TO 706                             SEC04360
705 CONTINUE                                                            SEC04370
706 DO 710 IINY=1,INY                                                   SEC04380
    DO 710 IIY=1,IY                                                     SEC04390
    DO 707 M=1,IY                                                       SEC04400
    IF (INAY(IINY,IIY).EQ.NSY(M)) GO TO 708                             SEC04410
707 CONTINUE                                                            SEC04420
708 CELL(I,J,M,N)=CELL(I,J,M,N)+TCELL(I,J,IIY,IIX)*                     SEC04430
   2                  PDSY(IINY)*PDSX(IINX)                             SEC04440
710 CONTINUE                                                            SEC04450
    RETURN                                                              SEC04460
    END                                                                 SEC04470
```

LIST OF REFERENCES

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